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TEN YEARS OF TESTING A 10 KILOWATT WIND-ELECTRIC SYSTEM FOR SMALL SCALE IRRIGATION

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Summary:

Ten years of research involving a 10 kilowatt wind turbine used for pumping water is documented in this paper. Daily water volumes using this wind turbine are shown for different pumps, well depths, and wind speeds which will help a farmer select the optimum centrifugal pump. If a cotton field doesn't have access to utility power, the cotton production on a 10 acre area can be increased 50% with this wind turbine for a pumping depth of 60 meters if the wind resource is similar to that of Bushland, Texas. However, before these wind turbines are used for small scale irrigation, some improvements should be made to the wind-electric system which are discussed in this paper.

Keywords:

Water Pumping, Irrigation, Cotton, Wind Turbine, Wind Energy

TEN YEARS OF TESTING A 10 KILOWATT WIND-ELECTRIC SYSTEM FOR SMALL SCALE IRRIGATION[1]

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ABSTRACT

Testing began on a 10 kW wind-electric water pumping system at the USDA-ARS Conservation and Production Research Laboratory in 1988. The wind-electric water pumping system initially consisted of a wind turbine, a tower, a submersible or surface mounted motor, and centrifugal pumps. A controller was added to the wind-electric system in 1989. The controller that was used from 1989 to 1995 was designed by USDA-ARS/WTAMU-AEI personnel. The smart controller used from 1995 to the present was designed by the wind turbine manufacturer based on the USDA/WTAMU prototype. The flexible wind turbine blades used from 1988 to 1992 developed cracks in the blades and were replaced by stiffer blades in 1993. On January 17, 1996, there was a failure in the upper guy cable attachment in winds gusting up to 27 m/s, but quick action by the wind energy team averted a complete failure of the wind turbine and tower by using a heavily loaded pickup truck as a guy anchor. Over the past year the performance of the wind turbine permanent magnet alternator has degraded, however the cause of the degradation has not been determined. The best motor to use with this wind-electric alternator is a 5.6 kW, 230 V, 3-phase motor. Depending on the pumping depth and the wind resource, 3.8 kW centrifugal pumps with differing numbers of stages should be used. For a 60 m well, enough water can be pumped by this wind-electric system to water 10 acres of cotton assuming a wind resource similar to that of Bushland, TX and increase the production by 50%. Before wind-electric systems are used for irrigation in large numbers, some improvements have to be made to the wind-electric water pumping system which are discussed in the paper.

INTRODUCTION

Mechanical windmills are currently being used all over the world to pump water in daily water volumes of 1000 to 20,000 ℓ/d. Some farmers and ranchers are replacing their aging windmills with wind-electric and solar water pumping systems. However, for daily water volumes greater than 20,000 ℓ/d at well depths greater than 50 m, the only stand-alone(no utility intertie) option, besides using a diesel generator, is to use a 10 kW or larger wind turbine with a permanent magnet alternator. Although utility electricity is fairly abundant and cheap in the Great Plains at

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the present time, as deregulation continues and a leveling of the prices occurs across the country, the price of utility supplied electricity to remote locations will probably increase significantly.

HISTORY OF BERGEY EXCEL-PD WIND-ELECTRIC WATER PUMPING TESTING

Wind-electric water pumping research began at the USDA-ARS Conservation and Production Research Laboratory in Bushland, TX, in 1987. Two 10 kW wind turbine permanent magnet alternators (a Windworker[3] 10 and a Bergey Windpower[3] Excel) were tested using a dynamometer which could run the alternators at varying speeds (frequencies) to determine how well the alternators would run in a variable wind speed environment (Clark, 1988). It was learned during this testing that off-the-shelf submersible motors and pumps could pump water efficiently (without using an inverter) if the V/f (Voltage to frequency ratio) was maintained close to the name plate value (230V/60Hz=3.8V/Hz). This proper V/f ratio could be maintained if the proper amount of capacitance was added in parallel with the submersible motor.

A Bergey Excel-PD wind turbine was installed at the Bushland site in March 1988 on a Rohn[3] guyed 45G lattice tower. The reason for the -PD designation is to differentiate this wind turbine from one used for battery charging or connected to the utility -- each of these alternators have a different stator winding. Table 1 shows a chronological history of testing on the Bergey Excel-PD. A controller was designed for this wind-electric system in a cooperative agreement between USDA-ARS and WTAMU-AEI (West Texas A&M University -- Alternative Energy Institute), and this controller was installed in March 1989. Both a low and a high stage pump were tested with this wind turbine and controller (Clark, 1989). Both pumps used a motor rated at 5.6 kW. In April 1992, blade root cracks were discovered in the flexible blades. In July 1993, extra stiff blades were installed and no more cracks in the blades have occurred.

Since the optimum motor and pump for various pumping depths is different for the Bergey Excel-PD than when using utility supplied electricity, several motors and pumps have been tested. Different size motors were tested with this wind turbine and controller to insure that the 5.6 kW motor was the proper motor size (Clark, 1995). All the pumps and motors tested on the Bergey Excel-PD are off-the-shelf and can be found virtually anywhere in the world. Both submersible and surface mounted motors and pumps were tested on the Bergey Excel-PD. The surface mounted motor/pumps tested included:

1. 5.6 kW 230 V 3ϕ AC motor with 17.8, 20.3, and 25.4 cm diameter impellers for the single-stage centrifugal pump.
2. 7.5 kW 230 V 3ϕ AC motor with 17.8, 20.3, and 25.4 cm diameter impellers for the single-stage centrifugal pump.

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[3]The mention of trade or manufacture names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA - Agricultural Research Service.

The submersible motors tested on this wind-electric system included:

1. 10 cm diameter 3.8 kW and 5.6 kW 230 V 3ϕ AC motors
2. 15 cm diameter 3.8 kW, 5.6 kW, and 7.5 kW 230 V 3ϕ AC motors.

The submersible pumps tested on this wind-electric system included:

1. 10 cm diameter 3.8 kW 15-stage, 20 stage, 26-stage, and 42-stage pumps
2. 15 cm diameter 5.6 kW 4-stage pump
3. 15 cm diameter 3.8 kW 5-stage pump.

The performance of the 3.8 kW and 5.6 kW motors was about the same for wind speeds below 10 m/s, but the 3.8 kW motor stayed online more of the time at higher wind speeds. However, the USDA/WTAMU controller didn't have thermal protection like the current Bergey controller, so two 3.8 kW motors were burned up during this testing. The 10 cm diameter 5.6 kW motor lasted several years before it was burned up during testing in Garden City, TX. Because of the 5.6 kW motor's durability and performance, it is the best size motor to use with the Bergey Excel-PD.

In January 1995, the production model Bergey Excel-PD controller was installed. Although the thermal protection was an improvement over the old controller, other discrepancies were found with the new controller (Vick, 1995). A reoccurring problem on both controllers was burned wires connecting the capacitors. The burned wires were caused by poor connection of spade connectors of the wires on the capacitors. The spade connectors were removed and the wires were directly soldered to the capacitors in October 1995 and no more burned wires have occurred. Several times when the controller battery voltage got low due to low wind days or icing of wind turbine blades, the fuses would blow in the battery charging circuit which resulted in down time. A recommended modification to the battery charging circuit by Bergey Windpower was implemented in February 1998 and no fuses have blown since that time. Also, this controller did not read frequencies above 99 Hz correctly. The controller could not distinguish between 42 Hz and 142 Hz, so sometimes the controller would cut the motor in at high frequencies.

During testing of this wind-electric system during 1994 and 1995, large amounts of offline data were discovered for wind speeds between 10 and 16 m/s. In order for the motor/pump combination to pump water, the wind turbine generator needs to stay synchronized (voltage and current in phase with each other) with the motor and pump. This is usually accomplished by adding the proper amount of capacitance. At a wind speed of 13 m/s this wind turbine will reach 90 Hz and since the current is above the rated current for the motor, it is desirable to disconnect the motor from the wind turbine via a high frequency cut-out. Also, the turbine will not be able to synchronize with the motor until the wind speed decreases to about 10 m/s (approx. 60 Hz) or the wind speed increases above 16 m/s where the wind turbine will furl and get back online. The deeper the pumping depth -- the lower the frequency needs to be before the wind turbine will synchronize with the motor. Besides the poor pumping performance in the 10 - 16 m/s wind speed range, the wind turbine makes considerable noise and vibrates the tower and the guy cables excessively in this wind speed range when it is running off line.

On January 17, 1996, the ground attachment of the upper guy cable failed in 27 m/s winds and catastrophic destruction of the wind turbine was averted by quick action of the wind energy group at Bushland. The Big Grip[3] attachment that failed connected a turn buckle (which was attached to an anchor rod) to the guy cable. The loose end of the detached guy cable was attached to the rear bumper of a 3/4 ton pickup truck. However, the pickup continued to be dragged around by the swaying tower with the 463 kg wind turbine on top. When a pallet load of cement was loaded into the back of the pickup, the heavily loaded pickup made a good guy anchor. Since running offline at high wind speeds probably caused the guy attachment failure (due to excessive vibration of the guy cable), research was begun on trying to reduce the furling wind speed or reduce the amount of time the wind turbine was offline (Vick, 1996). Although using trailing edge flaps on the blades didn't reduce the furling wind speed, the amount of offline time at high wind speeds was decreased because the trailing edge flaps slowed the rotor down because of the increased drag. The trailing edge flap drag also resulted in decreased performance at low wind speeds, so other ways of decreasing the offline time were sought. A computer analysis showed that changing the pitch of the blades should result in an improvement in pumping performance at low wind speeds, and a decrease in the amount of offline time at high wind speeds (Vick & Clark, 1997). Changing the pitch did indeed improve the pumping performance at low wind speeds (see RESULTS section in this paper), but the offline time actually increased at high wind speeds.

Two Bergey Excel-PD's were installed in July 1995 near Garden City, TX, for cotton irrigation (Vick et al., 1997). The measured flow rates on the actual wells near Garden City, TX, compared very well to flow rates measured at Bushland for simulated pumping depths using a pressure valve. Field experience at the wells near Garden City, TX, showed some deficiencies in using wind-electric systems for irrigation. Some of these deficiencies included:

1) When the wind-electric system was down, it was difficult to determine whether the problem was with the wind turbine, controller, motor, pump, or wiring. If another motor could be connected to the controller, the problem could be determined to be with the wind turbine and controller if it didn't work, and with the motor, pump, or wiring if it did work.
2) The motors and pumps usually used in the irrigation wells were 480 V, but the motors the Bergey Excel-PD was designed for were 230 V -- this meant new motors were required and the 230 V motors couldn't be checked at the site with the 480 V utility line. The only solution for this problem would be for the wind turbine manufacturer to design the wind turbine to supply 480 V.
3) Because of the variability of the wind, the farmer was unsure how much water was getting on each row of cotton. A solution to this problem would be to fill a storage tank first and use gravity feed to empty the tank onto the rows when it reached a certain volume.

Since the farmers using the Bergey Excel-PD's for irrigation were losing money by not using the utility supplied electricity for irrigating, the Bergey Excel-PD's will be removed. However, if the farmers didn't have access to utility supplied electricity or the cost of the utility supplied electricity was two to three times as high -- the Bergey Excel-PD's would be cost effective for irrigating the farmers' cotton.

CURRENT WIND-ELECTRIC WATER PUMPING CONFIGURATION

The current wind-electric water pumping configuration includes the following:

1) Wind turbine
2) Tower
3) Controller
4) Submersible Motor and Pump
5) Pipe from the pump in the well to the surface
6) Wire connecting the wind turbine to the controller and from the controller to the motor.

In most cases and especially for irrigation, there should be a storage tank for the water.

The wind turbine used was a Bergey Windpower[3] Excel-PD rated at 10 kW at a wind speed of 12.1 m/s, and had a rotor diameter of 7 m (23 ft). This upwind 3-bladed wind turbine has a tail for directional control. The blade material is epoxy fiberglass, and the blades are made using a pultrusion process which results in the blade having no static twist. A pitch weight is mounted on the outboard leading edge of the blade to control flutter, and to change the twist dynamically at high wind speeds. Overspeed is controlled by furling (wind turbine rotor turns the wind turbine out of the wind due to an offset between the yaw and rotor axis at a certain wind speed -- similar to a mechanical windmill). The generator is a permanent magnet alternator (PMA) which generates 3ϕ, variable voltage, variable frequency, AC electricity. The PMA is direct drive, so there is no gearbox. No brushes are necessary because the magnets rotate around the windings in the stator. A winch attached at the base of the tower is connected to the tail via a steel cable and allows the wind turbine to be manually furled.

Two controllers have been used on this wind-electric water pumping system as was mentioned previously in the HISTORY section. The main function of the controller is to allow the blades to get up to a certain rotational speed (where the angle-of-attack of the blades with-respect-to the relative wind maximizes the lift-to-drag ratio) before switching the electricity from the wind turbine to the motor. The rotational speed or frequency where this occurs at is known as the low frequency cut-in. There also is a high frequency cut-out which disconnects the wind turbine electricity from the motor. The high frequency cut-out protects the motor and wind turbine alternator from experiencing high current at high wind speeds. Another frequency setting is high frequency cut-in. This frequency is necessary for switching the load back on the wind turbine after the high frequency cut-out has been exceeded (high frequency cut-in should always be below high frequency cut-out). The last frequency setting is the low frequency cut-out. This frequency is needed to keep the wind turbine rotor speed from slowing too much due to the load on the wind turbine, and also not to cause excessive drain on the battery by keeping the mechanical relay engaged. The low frequency cut-out should always be below the low frequency cut-in. All of these frequencies were adjustable on both controllers. Another purpose of the pump controller is to add capacitance (motor run capacitors) in parallel with the well motor, in order to improve the power factor and keep from having to use an inverter -- i.e. decrease the cost of the system and improve the system efficiency. The Bergey Windpower controller also had some additional features. It had an adjustable thermal cut-out which would disconnect the wind turbine from the motor if the current stayed above a certain value for a certain length of time. Also on this controller was a manual/automatic switch. If the controller cut-out due to a thermal trip-out and the switch was on manual, an operator would have to physically reset the controller to allow the wind turbine to be loaded again. If the switch was on automatic the controller would switch the load back on the wind turbine after the system had cooled down to acceptable levels. There are other features on the Bergey controller that weren't tested, but can be found in Bergey Windpower's operating manual.

DATA ACQUISITION SYSTEM AND INSTRUMENTATION

Figure 1 shows a schematic of the wind-electric water pumping system. The electricity from the wind turbine is connected to a double throw switch in the wind laboratory building with 6 gauge wire. The double throw switch allows either electricity from the wind turbine or the utility to be supplied to the controller. The controller is connected to the submersible motor in an underground sump with 10 gauge wire. The submersible motor drives a centrifugal pump which pumps water to the surface. A back pressure tank is used to maintain pressure when the pump quits pumping water. A flow meter measures the flow rate and is calibrated with a weir at the discharge end of the pipe. Pressure is measured both with a pressure transducer and a mechanical pressure gage to determine the equivalent pumping depth. A pressure valve is used to set the pressure, so different pumping depths can be simulated. The data acquisition system used is a Campbell[3] 21X which stores and converts the instrumentation signals into usable engineering units. Analog data is collected every second and the average value is recorded every minute on a storage module. The pulse data is accumulated for each 10 seconds and the average of the 6 accumulated values are recorded every minute on a storage module. The data on the storage module was downloaded on a computer, and the data was processed using "C" computer programs. Processing the data allowed problems with the wind-electric system or the instrumentation to be uncovered. The data collected on this wind-electric system included:

1) Wind speed at hub height of wind turbine (pulse)
2) Power of wind turbine (analog)
3) Voltage of wind turbine (analog)
4) Current of wind turbine (analog)
5) Frequency of wind turbine (pulse)
6) Flow Rate of water pumping system (pulse)
7) Pressure of water pumping system (analog)
8) Julian day, hour, minute

RESULTS

Determining the optimum pump to be used for different pumping depths and different average wind speeds has been a primary objective in conducting research on this wind-electric water pumping system. The motor/pump combination that has been tested the longest is the 5.6 kW motor and the 3.8 kW 15 cm 5-stage pump. Figure 2 shows the flow rate versus wind speed at different pumping depths for this motor/pump combination. As the pumping depth (head) increases, the maximum flow rate decreases and the cut-in wind speed increases. Because the cut-in wind speed is affected by the number of stages in the pump, the optimum pump depends on the wind speed regime in addition to the pumping depth. The pumping performance of a 3.8 kW 10 cm 15-stage pump is shown in Figure 3. Although the maximum flow rates have decreased compared to the 5-stage pump, water begins pumping at a lower wind speed. Again the same trends in flow rate can be seen for the 3.8 kW 10 cm 26-stage pump (Figure 4). In order to determine the optimum pump for each pumping depth range, the monthly daily water volumes need to be estimated. If the monthly wind distribution is multiplied by the flow rate then monthly daily water volumes can be estimated. Figure 5 shows the average monthly wind speed for Bushland, TX, at a height of 18.5 m over the past two years. Because wind power is proportional to the cube of the wind speed, a small change in wind speed can result in a large increase in wind power. April has the highest average wind speed (7.3 m/s) compared to August which has the lowest (5.2 m/s). Figure 6 shows a comparison of the wind distribution for these two months. Figure 7 shows the daily water volume for the 5 and 15-stage pumps at a pumping depth of 40 m. It is obvious from this graph that the optimum pump depends not only on the pumping depth, but also on the wind speed. The 5-stage pump is optimum for the months with an average wind speed above 6 m/s, but the 15-stage pump is optimum for average wind speeds below 6 m/s. Figure 8 shows that for an 80 m pumping depth the 15-stage pump is optimum for higher wind speeds, but the 26-stage pump is the better choice for lower wind speed months. The last daily water volume graph is for 120 m and the 26-stage pump is the optimum pump for all the months of the year when compared to the 15-stage pump (Figure 9).

One of the ways which was investigated for reducing the furling wind speed for the Bergey Excel-PD was to decrease the pitch angle of the blades from 10 to 6 degrees. Although the furling wind speed was not reduced by reducing the pitch angle, the performance was increased by positioning the blade at a more optimum angle-of-attack (i.e. higher lift/drag ratio). The power data (corrected to standard day at sea level) is shown in Figure 10. This wind turbine was rated at 10 kW for a wind speed of 12.1 m/s and a pitch setting of 10 degrees. This rating was indeed confirmed as shown in Figure 10. The measured data also shows a progressive improvement in power with wind speed for lowering the pitch angle. Figure 11 shows the substantial improvement in power coefficient for reducing the pitch angle from 10 to 6 degrees. The increase in power for the wind turbine results in an increase in flow rate (Figure 12). Figure 13 shows that the reduced pitch angle will increase the daily water volume 10 to 25% assuming monthly wind distributions that were used for Figures 7-9. However, Figure 14 shows how the "ON" time decreases with a lower pitch angle.

Figure 15 illustrates how the open circuit voltage has decreased since February 1997. Some of the mid range frequency data is not shown during some of the time periods because the motor/pump was connected to the wind turbine, and the only available open circuit voltage and frequency data was that before low frequency cut-in and after high frequency cut-out. A drop in open circuit voltage at a certain frequency implies a performance degradation in the PMA. What is causing the performance degradation in the PMA is not know at this time, but when the PMA is removed from the tower and inspected, a cause should be determined.

CONCLUSIONS

During the ten years of testing a 10 kW wind-electric water pumping system, much has been learned. A controller (preferably a smart one) is needed to connect and disconnect the wind turbine to the motor at the proper time. The motor can run efficiently off the variable voltage/frequency 3ϕ AC electricity generated by the wind turbine PMA as long as the proper amount of capacitance is added in parallel to the motor -- an inverter is not needed. The optimum motor for this wind turbine is a 5.6 kW, 230 V, 3ϕ, AC motor. The optimum pump depends on the pumping depth and the wind speed distribution. The major problem currently with this wind-electric system is the amount of offline time that occurs in the wind speed range of 10-16 m/s. If the furling wind speed can be decreased from 16 - 18 m/s to 13 m/s, the offline time in this wind speed range can be reduced to virtually zero. Decreasing the pitch angle from 10 degrees to 6 degrees will increase the pumping performance, but it will increase the offline time at higher wind speeds, so the pitch angle should not be reduced until the offline time at higher wind speeds is corrected. The lower pitch setting needs a higher wind gust to get the rotor turning, but additional leading or trailing edge camber at the blade root would correct for this deficiency. The Bergey Excel-PD PMA performance is steadily decreasing and at the present time the reason for the degradation has not been determined. Before Bergey Excel-PD's are used extensively for small scale irrigation, solutions to the above discussed problems need to be found. In addition, the following should also be done for wind-electric small scale irrigation to be successful:

1) A storage tank should be used so an even watering of the plants can be performed.
2) An extra motor should be located close to the controller to determine if problem with wind turbine/controller or motor/pump/wiring.

FUTURE WORK

We plan on testing a new PMA designed by Bergey Windpower later this year. We also may test a modified set of blades to try to reduce the furling wind speed based on the furling testing we have been conducting on the smaller wind turbines at USDA-ARS. Another possibility for decreasing the offline time in the 10 to 16 m/s wind speed range is to install an inexpensive inverter -- research is currently being done on an inexpensive inverter for the Bergey Excel-PD.

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TABLE 1. HISTORY OF BERGEY EXCEL-PD (10 KW) TESTING AT BUSHLAND, TX FOR WATER PUMPING

MONTH	YEAR	MOTOR TYPE	CENTRIFUGAL PUMP TYPE	CONTROL TYPE	FREQ. CUT-OUT	CAP./ PHASE	CAP. CONN.	CONTROL MODIFIED	BLADES	T.E. FLAPS	PITCH (DEG)	TUFTED BLADE
Mar.	1988	5.6kW(10cm)	5.6kW(17.8cm) 1 stage	None	N/A	170 uF	Spade	N/A	Flexible	None	10	No
June	•	•	3.8kW(10cm) 42 stages	•	•	•	•	•	•	•	•	•
Oct.	•	•	5.6kW(17.8cm) 1 stage	•	•	•	•	•	•	•	•	•
Mar.	1989	•	•	ARS/AEI	90 Hz.	150 uF	•	•	•	•	•	•
Sep.	•	•	3.8kW(15cm) 5 stages	•	•	•	•	•	•	•	•	•
Oct.	•	•	5.6kW(17.8cm) 1 stage	•	•	•	•	•	•	•	•	•
Dec.	•	7.5kW(15cm)	•	•	•	•	•	•	•	•	•	•
Jan.	1990	•	5.6kW(20.3cm) 1 stage	•	•	•	•	•	•	•	•	•
Apr.	•	•	5.6kW(25.4cm) 1 stage	•	•	•	•	•	•	•	•	•
Jul.	•	•	3.8kW(15cm) 5 stages	•	•	•	•	•	•	•	•	•
Oct.	•	5.6kW(10cm)	•	•	85 Hz.	•	•	•	•	•	•	•
Jan.	1992	•	5.6kW(20.3cm) 1 stage	•	•	•	•	•	•	•	•	•
Apr.	•	•	3.8kW(15cm) 5 stages	•	•	•	•	•	•	•	•	•
July	1993	•	•	•	•	•	•	•	Stiff	•	•	•
Jan.	1994	•	•	•	•	•	•	•	•	•	•	•
•	•	7.5kW(15cm)	5.6kW(15cm) 4 stages	•	•	200 uF	•	•	•	•	•	•
Mar.	•	•	•	•	•	255 uF	•	•	•	•	•	•
•	•	5.6kW(10cm)	3.8kW(15cm) 5 stages	•	120 Hz.	150 uF	•	•	•	•	•	•
June	•	5.6kW(15cm)	5.6kW(15cm) 4 stages	•	•	•	•	•	•	•	•	•
•	•	3.8kW(10cm)	3.8kW(15cm) 5 stages	•	•	100 uF	•	•	•	•	•	•
•	•	•	•	•	•	150 uF	•	•	•	•	•	•
July	•	5.6kW(10cm)	•	•	•	100 uF	•	•	•	•	•	•
•	•	3.8kW(15cm)	5.6kW(15cm) 4 stages	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	150 uF	•	•	•	•	•	•
•	•	7.5kW(15cm)	•	•	100 Hz.	250 uF	•	•	•	•	•	•
•	•	5.6kW(10cm)	3.8kW(15cm) 5 stages	•	•	200 uF	•	•	•	•	•	•
Aug.	•	•	•	•	•	150 uF	•	•	•	•	•	•
Sep.	•	•	•	•	120 Hz.	•	•	•	•	•	•	•
•	•	3.8kW(10cm)	•	•	•	100 uF	•	•	•	•	•	•
Oct.	•	•	•	•	75 Hz.	150 uF	•	•	•	•	•	•
Nov.	•	•	•	•	85 Hz.	•	•	•	•	•	•	•
Jan.	1995	•	•	Bergey	•	•	•	No	•	•	•	•
Mar.	•	5.6kW(10cm)	3.8kW(10cm) 15 stages	•	•	•	•	•	•	•	•	•
Apr.	•	•	•	•	•	100 uF	•	•	•	•	•	•
•	•	•	•	•	•	150 uF	•	•	•	•	•	•
July	•	•	•	•	•	200 uF	•	•	•	•	•	•
Oct.	•	•	•	•	•	•	Soldered	•	•	•	•	•
Mar.	1996	•	•	•	•	•	•	•	•	TEF#1	•	•
•	•	•	•	•	•	350 uF	•	•	•	•	•	•
•	•	•	•	•	•	200 uF	•	•	•	•	•	•
•	•	•	3.8kW(15cm) 5 stages	•	•	150 uF	•	•	•	•	•	•
Apr.	•	3.8kW(10cm)	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	None	•	•
May	•	•	•	•	•	•	•	•	•	TEF#2	•	•
June	•	•	•	•	•	•	•	•	•	TEF#3	•	•
Aug.	•	•	•	•	•	•	•	•	•	•	•	Yes
Oct.	•	•	•	•	•	•	•	•	•	None	8	No
Dec.	•	5.6kW(10cm)	3.8kW(10cm) 15 stages	•	•	•	•	•	•	•	•	•
Mar.	1997	•	•	•	•	•	•	•	•	•	10	•
June	•	•	3.8kW(10cm) 26 stages	•	•	•	•	•	•	•	•	•
Nov.	•	•	3.8kW(10cm) 20 stages	•	•	•	•	•	•	•	•	•
Feb.	1998	•	•	•	•	•	•	Yes	•	•	•	•
Mar.	•	3.8kW(10cm)	3.8kW(15cm) 5 stages	•	•	•	•	•	•	•	•	•

PROBLEMS

1. CRACKS IN FLEXIBLE BLADES.
2. BURNED UP WIRES CONNECTING CAPACITORS, ALSO CAPACITORS GETTING HOT.
3. NO C/B TRIP WHEN HIGH CURRENT(BURNED UP TWO 3.8 KW MOTORS IN 1994).
4. EXCEL RUNS OFFLINE A LARGE % OF TIME FOR WIND SPD RANGE 11-16 M/S.
5. BERGEY CONTROLLER BLOWS FUSES OFTEN IN BATTERY CHARGING CIRCUIT.
6. BERGEY CONTROLLER CUTS IN WIND TURBINE AT HIGH FREQUENCIES.
7. BIG GRIP FAILURES ON GUY CABLES. ALMOST LOST TURBINE/TOWER,1-17-96.
8. DEGRADATION IN PERFORMANCE OF BERGEY EXCEL ALTERNATOR AFTER 10 YRS.

SOLUTIONS

1. USE STIFFER BLADE OPTION.
2. NO MORE PROBLEMS AFTER SOLDERING WIRES.
3. USE BERGEY CONTROLLER (HAS THERMAL TRIP).
4. HAVEN'T DETERMINED A COST EFFECTIVE SOLUTION.
5. MODIFY BATTERY CHARGING CIRCUIT ON CONTROLLER CIRCUIT BOARD.
6. MODIFY CONTROLLER CPU OR MAKE WIND TURBINE FURL SOONER.
7. REPLACE BIG GRIPS EVERY 5 YEARS.
8. FIRST DETERMINE IF DEGRADATION DUE TO STATOR OR MAGNETS.

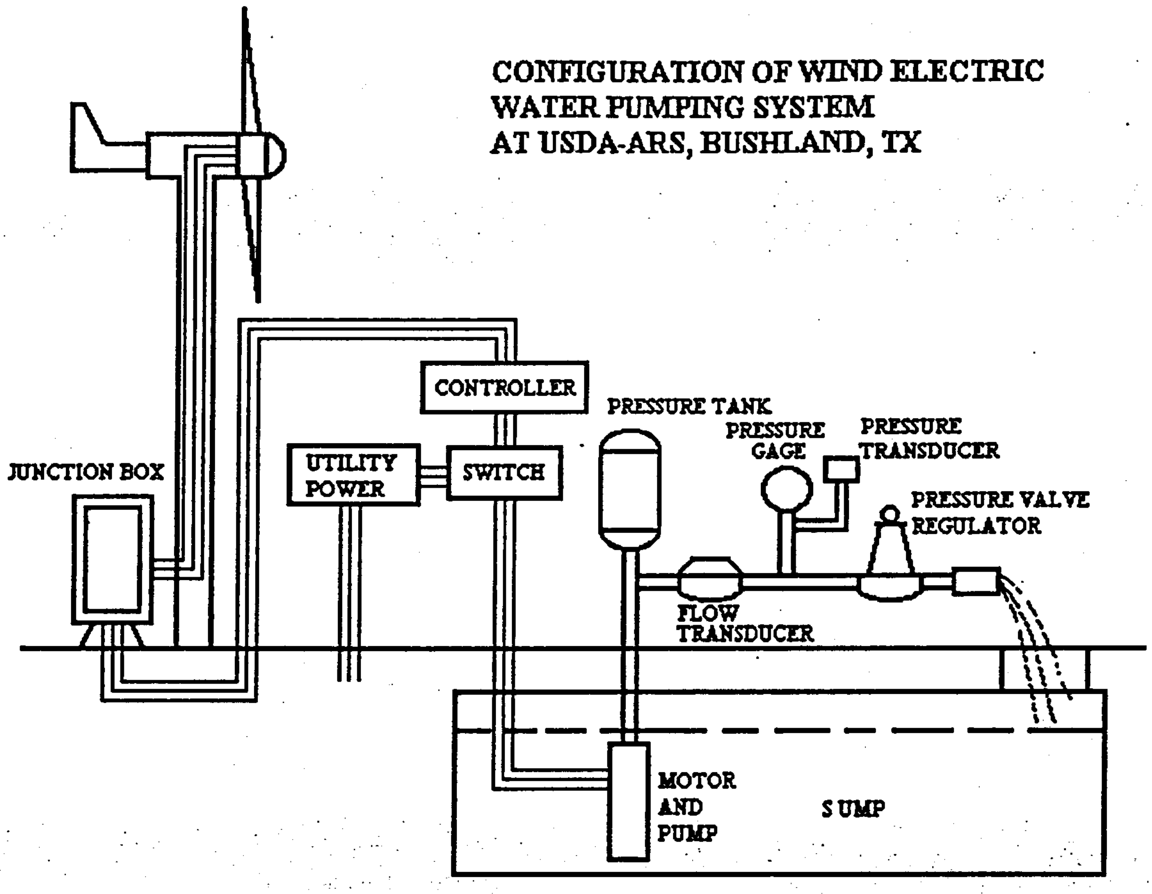

Figure 1. Schematic of Wind-Electric Water Pumping System at the USDA-ARS, Bushland, TX.

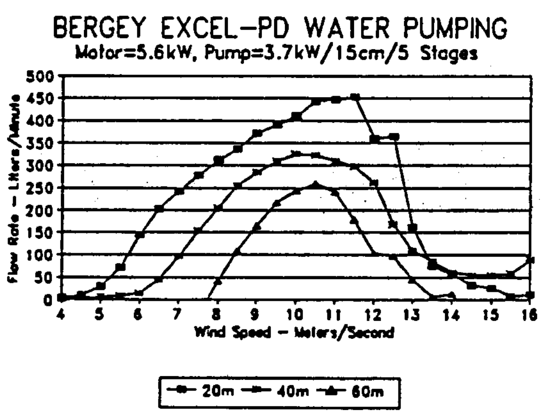

Figure 2. Flow Rate of Bergey Excel-PD with 5 Stage Pump.

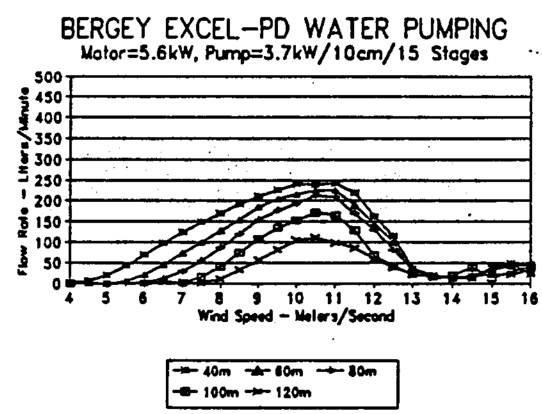

Figure 3. Flow Rate of Bergey Excel-PD with 15 Stage Pump.

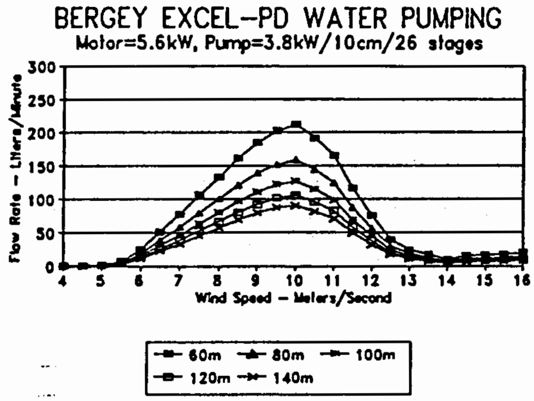

Figure 4. Flow Rate of Bergey Excel-PD with 26 Stage Pump.

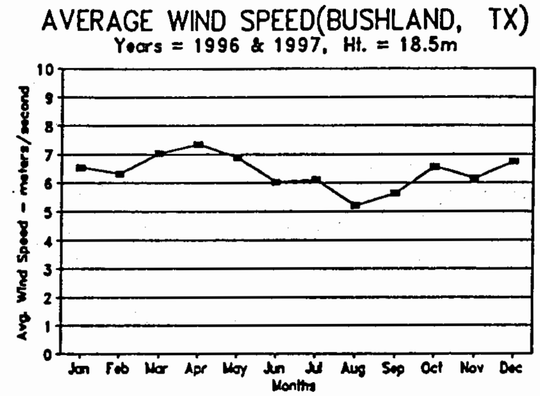

Figure 5. Average Wind Speed from 1996 to 1997 at 18.5m ht. at Bushland, TX

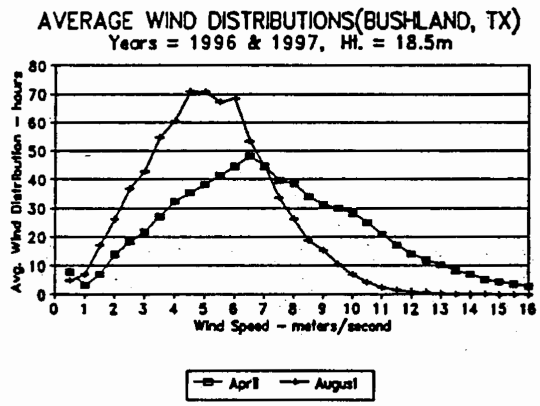

Figure 6. Average Wind Dist. from 1996 to 1997 at 18.5m ht. at Bushland, TX

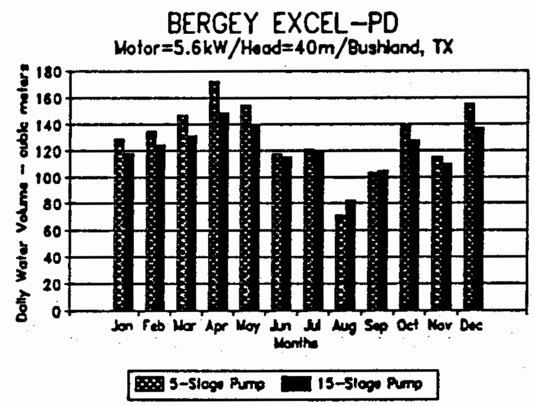

Figure 7. Daily Water Volume of Bergey Excel-PD for 5 and 15 Stage Pumps at a 40m Head.

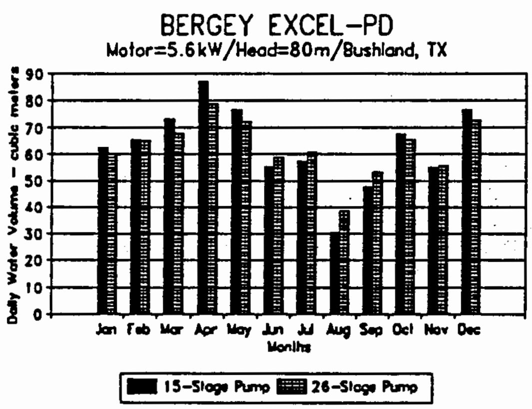

Figure 8. Daily Water Volume of Bergey Excel-PD for 15 and 26 Stage Pumps at a 80m Head.

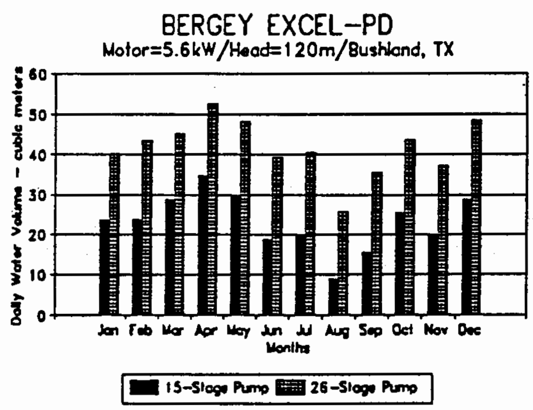

Figure 9. Daily Water Volume of Bergey Excel-PD for 15 and 26 Stage Pumps at a 120m Head.

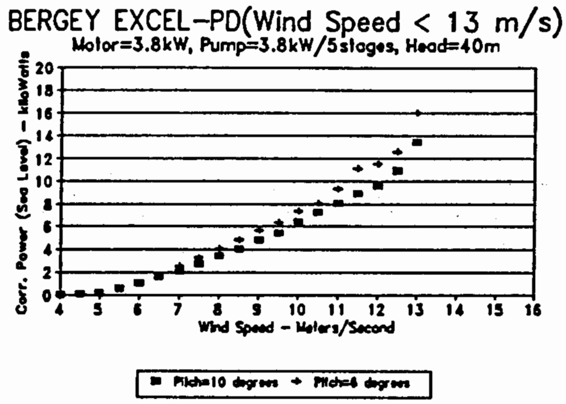

Figure 10. Power (Std.Day,S.L.) of Bergey Excel-PD at Pitch Settings of 10 and 6 degrees.

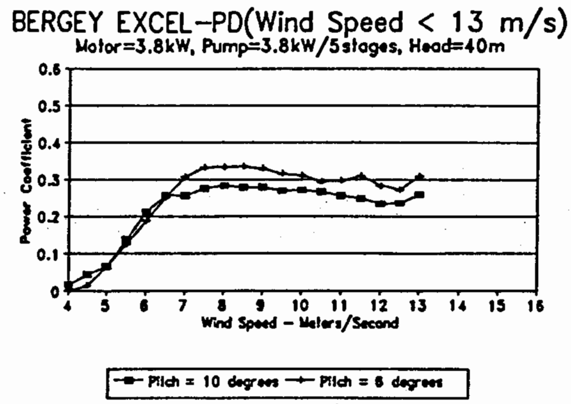

Figure 11. Power Coefficient of Bergey Excel-PD at Pitch Settings of 10 and 6 degrees.

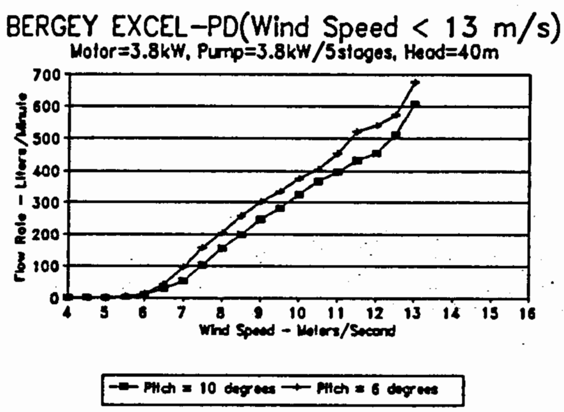

Figure 12. Flow Rate of Bergey Excel-PD at Pitch Settings of 10 and 6 degrees.

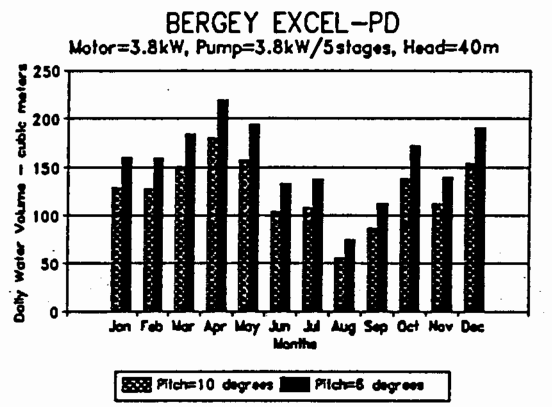

Figure 13. Daily Water Volume of Bergey Excel-PD for Pitch Settings of 10 and 6 degrees.

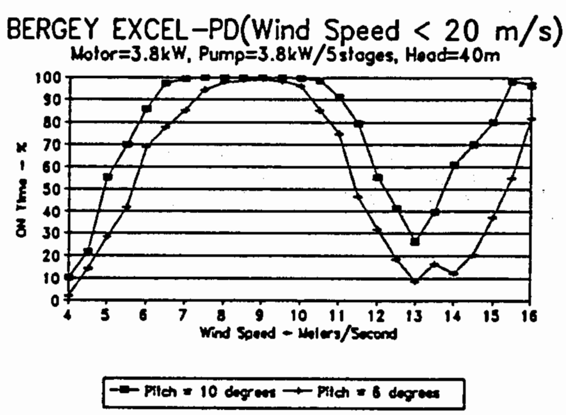

Figure 14. Percentage of "ON" Time for Bergey Excel-PD at Pitch Settings of 10 and 6 degrees.

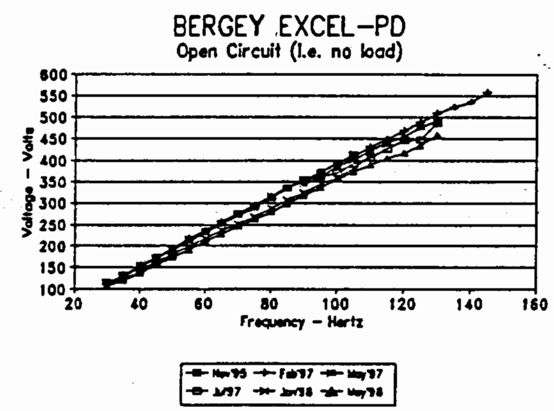

Figure 15. Open Circuit Voltage Versus Frequency for Bergey Excel-PD since 11/95.